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DOI:

[10.1177/1751143715577565](https://doi.org/10.1177/1751143715577565)

Document Version

Peer reviewed version

[Link to publication record in King's Research Portal](#)

Citation for published version (APA):

Bonnici, T., Charlton, P., Pierre, D., Tarassenko, L., Watkinson, P., & Beale, R. (2015). Experiences implementing a system for widespread recording of patient physiology. In *Journal of the Intensive Care Society: Clinical Practice, Research and Sepsis poster Presentations* (Vol. 16)
<https://doi.org/10.1177/1751143715577565>

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Experiences implementing a system for widespread recording of patient physiology

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Abstract

We describe the creation of a physiological database containing multi-parameter waveform data for the entirety of a patient's post-operative stay. Previous large-scale physiological databases have either been limited to patients within ICU or do not contain waveform data. Our system further improves on previous work in that it utilises commercially-available components, making it easy to implement, and is cost-effective to scale.

Introduction

Databases of physiological data have facilitated novel physiological analyses and the development of predictive models to improve processes and outcomes¹. Data with a relatively low temporal resolution can be extracted from intensive care Electronic Patient Record (EPR) systems. However, collection of high resolution data, most notably waveform data such as ECG, arterial pressure waveform and the pulse oximeter waveform (properly termed the photoplethymogram (PPG)), requires specialised software. Previously described systems to record waveforms are dependent on in-house software to interface with patient monitors or have infrastructure requirements that rapidly increase with each additional monitored bed added to the system.^{2,3} Furthermore, they have been restricted to the Intensive Care Unit (ICU) where patients are typically confined to their bed space. We report our experiences with the development of a system to record waveform and numeric physiological data from patients undergoing cardiac surgery for the entirety of their post-operative hospital stay.

Methods

Participants & Setting

Adults undergoing cardiac surgery at St Thomas' Hospital were recruited for this study. The hospital has a standardised post-operative cardiac surgery pathway. For the first 12-24 hours patients are monitored on a Level 3 post-operative unit. Patients are normally stepped down the the Cardiac High Dependency Unit (HDU) for a further 24-48 hours before being transferred to the Level 1 cardiac surgery ward. Any patient who subsequently deteriorates is transferred to either the Cardiac HDU or one of two general ICUs. Across the five wards patients there are 66 monitors – 56 fixed monitors and 10 telemetry devices.

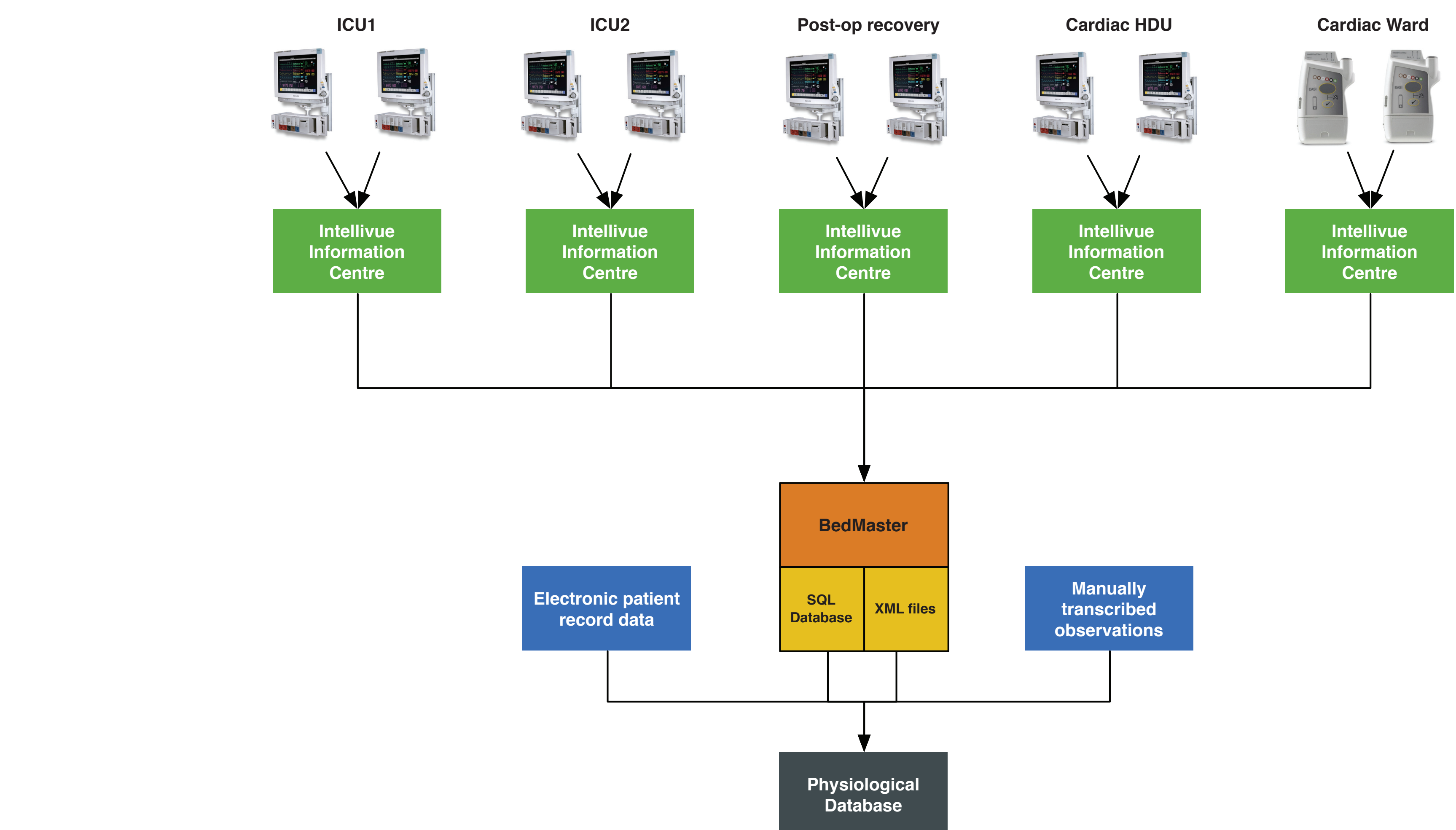
System Architecture

Hardware

Patients on the Level 2 and Level 3 units (HDU/ICU) were monitored according to standard practice using MP70 bedside monitors (Philips Medical Systems, Eindhoven). On the Level 1 ward, where the standard of practice is intermittent recording of vital signs, participants were asked to wear a telemetry monitor capable of recording both ECG and pulse oximetry data (Intellivue Telemetry M4841A Trx+SpO₂, Philips). Each ward had a dedicated “central station” (Intellivue Information Centre, Philips) with Web Serving functionality enabled. Physiological parameters not measured by the telemetry (notably blood pressure, respiratory rate and temperature) were recorded by ward staff using spot check monitors and documented on the hospital's standard paper vital signs charts.

Software

BedMaster Ex software (version 4.1.12, Excel Medical Electronics) was used to record both waveform and numerical data. The software captured all data recorded by the monitor. Numeric values sampled every 5 minutes and all alarms were stored in a SQL database (SQL Server, Microsoft). Frequently sampled data from the monitors – numerics sampled every second and waveforms sampled at 125Hz – were stored outside the database in a proprietary data format and were retrospectively converted to XML files for data analysis. One file was created for each patient monitoring episode. Thus



every patient had a minimum of three files, one for each monitor used to record their physiology.

Physiological data not measured by the monitors was collected by retrospective querying of the HDU/ICU EPR (IntelliVue Clinical Information Portfolio, Philips) and manual transcription of ward paper charts.

Data Recording & Handling Procedures

The times when patients entered and exited each bed were determined from multiple hospital information systems. These were used to trim and concatenate the XML files containing high resolution physiological data to create a single record for each patient. Manual verification of each output file was required to ensure that no errors had occurred.

For the purposes of this analysis, only figures pertaining to ECG data are reported. Figures relating to PPG and the waveforms only recorded on HDU/ICU, such as the arterial blood pressure trace, are not reported here.

The duration for which data was recorded was calculated as the number of seconds in which a physiologically-plausible numeric was recorded. Results are reported for the entire patient stay and subdivided into the periods on HDU/ICU, where obligatory monitoring was part of standard care, and the periods on the Level 1 ward where patients could request to have the telemetry removed if they found it too uncomfortable. Unless otherwise specified, quoted figures are median values with the interquartile range in brackets.

Results

226 patients were recruited between November 2012 and January 2014. 4 patients withdrew, leaving 222 patients with data recorded on HDU/ICU. After being monitored on HDU/ICU, 23 patients were excluded as they deviated from the standard cardiac surgery pathway and 8 patients did not receive telemetry for either clinical reasons or patient request. Therefore 191 patients were monitored with telemetry. 64 patients removed the telemetry early, 7 patients had telemetry removed for clinical reasons and 2 patients were transferred to other wards leaving 118 patients who were monitored continuously for the entirety of their post-operative stay.

For the 191 patients assigned telemetry, the total post-operative length of stay was 7.1 days (5.8-11.1 days); 2.3 days (1.9-3.8 days) on HDU/ICU and 4.3 days (3.1-8.0 days) on the Level 1 ward. The median duration of telemetry monitoring was 3.7 days (2.5-5 days). The overall proportion of the patient stay for which ECG was recorded was 74% (59-85%); 94% (89-96%) on HDU/ICU and 68% (35-84%) on the Level 1 ward. The majority of data loss on the Level 1 ward was caused by patients requesting for the telemetry monitoring to be removed early. Restricted to the period for which patients

were wearing the telemetry monitors, data was recorded for 80% (66-88%) of the time.

All monitors in our system had the facility to “admit” (enter demographics) and “discharge” patients (erase demographics) from the monitor. BedMaster was configured to start recording when a patient was admitted to a monitor and cease on discharge. Data losses during the monitoring period were commonly caused by delays in admitting or discharging patients from the monitors. These tasks are often deferred in favour of clinical work. Some recordings required manual review to avoid attributing data to the wrong patient.

The potential for data loss or erroneous attribution increases with each admit/discharge episode. All but two patients were transferred between monitored beds at least once during their stay (median transfers = 3, maximum = 13).

Conclusions

To our knowledge this is the first description of a research-quality database containing continuous waveform data and all five standard vital signs from patients for the duration of their stay. Data was recorded for a high proportion of each patient's HDU/ICU stay. Recording of data using the telemetry monitors was slightly less successful due to patient intolerance of the monitoring equipment.

Our system has the benefit of being easy to implement and scale. The hardware requirements do not rapidly increase according to the number of monitors from which data is collected and in-house development of complex acquisition software was not required.

Nonetheless improvements can be made. In the absence of an electronic vital signs charting system, some physiological data had to be manually transcribed from paper charts. The planned introduction of an electronic system for recording vital signs will address this issue. Manual review was necessary to ensure no errors were made in combining all data pertaining to a patient. Further work will investigate solutions to facilitate fully automated recording of patient physiology at scale.

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Acknowledgement

This research was supported by the EPSRC [Grant EP/F058845/1], the National Institute for Health Research (NIHR) comprehensive Biomedical Research Centre at Guy's & St Thomas' NHS Foundation Trust, and the NIHR Oxford Biomedical Research Centre Programme. The views expressed are those of the authors and not necessarily those of the EPSRC, the NHS, the NIHR or the Department of Health.